MEGA LECTURE · A LEVEL CHEMISTRY

Chapter 11: Reaction Rates

OCR A Level Chemistry A (H432) — Structured Practice Worksheet

SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
3.1.5 Reaction rates: collision theory, Maxwell–Boltzmann, factors affecting rate, catalysis	88	1 hour 50 minutes

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Instructions to candidates

- Answer **all** questions in the spaces provided.
- Sketched graphs should have labelled axes.
- Marks are shown in brackets [ ] at the end of each part.

Question 1 — Collision theory

3.1.5

a. State the two conditions necessary for a collision between reactant particles to result in a reaction. **[2]**

b. Define *activation energy*. **[2]**

c. Explain why not every collision between reactant particles results in a reaction. **[2]**

d. Explain, using collision theory, why increasing the concentration of a reactant in solution increases the rate of reaction. **[3]**

Question 1 total: 9 marks

Question 2 — The Maxwell–Boltzmann distribution

3.1.5

a. Sketch the Maxwell–Boltzmann distribution of molecular energies for a fixed sample of gas at a constant temperature. Label the axes, mark the activation energy E_a, and shade the area representing particles with energy ≥ E_a. **[5]**

Sketch the Maxwell–Boltzmann distribution

b. State why the curve begins at the origin and does not touch the x-axis at high energy. **[2]**

c. On the same axes (or a second sketch), show the effect of increasing the temperature on the distribution, and describe how the curve changes. **[3]**

Sketch the higher-temperature curve

d. Explain, using the Maxwell–Boltzmann distribution, why a small increase in temperature causes a large increase in reaction rate. **[4]**

Question 2 total: 14 marks

Question 3 — Factors affecting rate: concentration and pressure 3.1.5

a. Explain, in terms of particle number and frequency of collisions, why increasing the concentration of a reactant increases the rate of reaction. **[3]**

b. Explain why increasing the pressure of a gaseous reaction mixture increases the rate of reaction. **[3]**

c.

A student doubles the concentration of a reactant in solution. Explain whether this doubles the frequency of successful collisions, the frequency of all collisions, or neither, distinguishing these two effects clearly. **[3]**

Question 3 total: 9 marks

Question 4 — Surface area

3.1.5 / PAG

A student investigates the effect of surface area on rate using marble chips (calcium carbonate) reacting with dilute hydrochloric acid, measuring the volume of CO_2 produced over time.

a. Explain, in terms of collision theory, why powdered marble reacts faster than large marble chips of the same total mass. **[3]**

b. Sketch, on the same axes, the volume of gas against time graphs for powdered marble and large marble chips of the same mass and the same excess acid concentration. Label each curve and mark the final volume of gas. **[3]**

Sketch both curves on the same axes

c. Explain why the total (final) volume of gas produced is the same for both experiments. **[2]**

d. State two variables that should be kept constant to make this a fair comparison. **[2]**

Question 4 total: 10 marks

Question 5 — Catalysts

3.1.5

a. Define *catalyst*. **[2]**

b. Explain, in terms of activation energy, how a catalyst increases the rate of a reaction. **[3]**

c. Sketch a Maxwell–Boltzmann distribution showing the activation energy for both the catalysed and uncatalysed pathway, and shade the additional area of particles able to react once the catalyst is added. **[3]**

Sketch both activation energies on the distribution

d. Explain why a catalyst does not appear in the overall balanced equation for a reaction. **[2]**

e. Distinguish between a *homogeneous* catalyst and a *heterogeneous* catalyst, giving one example of each. **[2]**

Question 5 total: 12 marks

Question 6 — Catalysts and the economy/environment 3.1.5

a. Explain why catalysts are economically important in industrial processes, referring to activation energy and reaction conditions (temperature/pressure). **[3]**

b. Explain how using a catalyst can reduce the environmental impact of an industrial process. **[3]**

c.

Explain why heterogeneous catalysts are often used as fine powders or on a support with a large surface area. **[2]**

Question 6 total: 8 marks

Question 7 — Practical: rate of reaction experiments

3.1.5 / PAG

The rate of the reaction between sodium thiosulfate solution and dilute hydrochloric acid is investigated using the "disappearing cross" method: $Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(g) + S(s) + H_2O(l)$

a. Describe how this experiment is carried out, and explain what causes the cross to disappear from view. **[3]**

b. State the dependent and independent variables in an experiment investigating the effect of thiosulfate concentration on rate. **[2]**

c. State two variables that must be controlled for a fair comparison between runs at different concentrations. **[2]**

d. Explain one limitation of using "time for the cross to disappear" as a measure of rate, in terms of subjectivity/reliability. **[2]**

e. The experiment is repeated at a higher temperature, keeping all concentrations the same. Predict and explain the effect on the time taken for the cross to disappear. **[3]**

Question 7 total: 12 marks

Question 8 — Interpreting rate data

3.1.5

In a series of experiments, the time for a fixed volume of gas to be produced was measured at different concentrations of a reactant, keeping temperature constant. As concentration increased, the time taken decreased.

a. Explain how "1 ÷ time" can be used as a measure of the rate of this reaction. **[2]**

b. Sketch a graph of rate (1/time) against concentration for a reaction that is first order with respect to the reactant. **[3]**

Sketch rate vs concentration

c. Explain, using collision theory, why the graph in (b) passes through the origin. **[3]**

Question 8 total: 8 marks

Question 9 — Extended response

Synoptic

Explain fully, using both collision theory and the Maxwell–Boltzmann distribution, why increasing the temperature of a reaction mixture by only 10 °C can approximately double the rate of a reaction, whereas doubling the concentration of a reactant typically only doubles the rate. Your answer should explain what changes (and what does not change) in each case. **[6]**

This question is marked using a level of response.

Question 9 total: 6 marks

PAPER TOTAL: 88 MARKS

MARK SCHEME — Chapter 11: Reaction Rates

Award marks independently unless stated.

Q1 (a) [2]

- Particles must collide with energy greater than or equal to the activation energy. (1)
- Particles must collide with the correct orientation. (1)

Q1 (b) [2]

- The minimum energy... (1)
- ...that colliding particles must possess for a collision to result in a reaction. (1)

Q1 (c) [2]

- Many collisions do not have sufficient energy (less than the activation energy). (1)
- Or the particles collide with the wrong orientation, even if energy is sufficient. (1)

Q1 (d) [3]

- Increasing concentration increases the number of reactant particles per unit volume. (1)
- This increases the frequency of collisions between reactant particles. (1)
- More collisions per second have energy ≥ E_a, so more successful collisions occur per second, increasing the rate. (1)

Q2 (a) [5]

- Axes correctly labelled: y-axis "number of particles/fraction of particles", x-axis "energy". (1)
- Curve starts at the origin (0,0). (1)
- Curve rises to a single peak (not symmetrical) then falls, approaching but not touching the x-axis at high energy. (1)
- E_a marked on the x-axis, positioned to the right of the peak. (1)
- Area under the curve to the right of E_a shaded. (1)

Q2 (b) [2]

- Origin: no particles have zero energy (all particles have some kinetic energy). (1)
- Does not touch the x-axis: a very small number of particles could theoretically have extremely high energy, so the curve only approaches the axis (asymptotic). (1)

Q2 (c) [3]

- New curve drawn flatter and broader/shifted to the right, with the peak at a higher energy. (1)
- Both curves start at the origin and have the same area under them (same total number of particles). (1)
- The peak of the new curve is lower than the original (curve is flatter). (1)

Q2 (d) [4]

- At the higher temperature, the distribution shifts so a greater proportion of particles have energy ≥ E_a. (1)
- This area under the curve beyond E_a increases disproportionately (much more than the temperature increase itself). (1)
- This leads to a large increase in the frequency of successful collisions (i.e. those with sufficient energy). (1)
- So even a small rise in temperature causes a large increase in rate, because the number of particles with E ≥ E_a increases sharply, not linearly with temperature. (1)

Q3 (a) [3]

- Higher concentration means more particles per unit volume. (1)
- Particles are closer together (on average), so collisions between reactant particles occur more frequently. (1)
- More frequent collisions means more successful collisions per second, so the rate increases. (1)

Q3 (b) [3]

- Increasing pressure of a gas mixture compresses the gas into a smaller volume. (1)
- This increases the concentration/number of particles per unit volume. (1)
- More frequent collisions between reactant particles, increasing the rate. (1)

Q3 (c) [3]

- Doubling concentration approximately doubles the frequency of *all* collisions (proportional to concentration). (1)
- The *proportion* of collisions with energy ≥ E_a (fraction that are "successful" if they occur) stays the same, since temperature/E_a are unchanged. (1)
- So the frequency of successful collisions also approximately doubles, along with the rate — but this is because there are twice as many collisions overall, not because a collision is more likely to succeed. (1)

Q4 (a) [3]

- Powdered marble has a much greater total surface area (for the same mass) than large chips. (1)
- More particles of calcium carbonate are exposed/accessible at the surface to collide with acid particles. (1)
- This increases the frequency of collisions (per unit time) between HCl and $CaCO_3$, increasing the rate. (1)

Q4 (b) [3]

- Both curves rise from the origin and level off at the same final volume. (1)
- Powder curve rises more steeply (faster initial rate) than the large chip curve. (1)
- Powder curve reaches the plateau (levels off) sooner than the large chip curve. (1)

Q4 (c) [2]

- Same mass of $CaCO_3$ (and the same excess of acid) is used in both experiments. (1)
- So the same amount (moles) of CO_2 gas is eventually produced in both cases, regardless of the rate. (1)

Q4 (d) [2]

- Volume/concentration of hydrochloric acid. (1)
- Temperature. (1)

Q5 (a) [2]

- A substance that increases the rate of a reaction... (1)
- ...without being used up / chemically unchanged at the end of the reaction (it provides an alternative reaction pathway). (1)

Q5 (b) [3]

- A catalyst provides an alternative reaction pathway/mechanism. (1)
- This alternative pathway has a lower activation energy than the uncatalysed route. (1)
- More particles now have energy ≥ this lower E_a, so more collisions are successful, increasing the rate. (1)

Q5 (c) [3]

- Standard Maxwell–Boltzmann distribution curve drawn. (1)
- Two activation energies marked, with E_a(catalysed) clearly to the left of (lower than) E_a(uncatalysed). (1)
- Additional shaded area between the two E_a values representing the extra particles now able to react. (1)

Q5 (d) [2]

- A catalyst is regenerated/reformed at the end of the reaction (it is not consumed). (1)
- So it does not appear as a net reactant or product in the overall stoichiometric equation. (1)

Q5 (e) [2]

- Homogeneous: catalyst is in the same physical state/phase as the reactants, e.g. Fe^{2+} catalysing the I^-/$S_2O_8^{2-}$ reaction, or acid catalysis in esterification. (1)
- Heterogeneous: catalyst is in a different physical state/phase from the reactants, e.g. iron in the Haber process, or a platinum/palladium/rhodium catalytic converter. (1)

Q6 (a) [3]

- A catalyst lowers the activation energy needed for the reaction. (1)
- This allows the reaction to be run at a lower temperature and/or pressure than would otherwise be needed. (1)
- Lower temperature/pressure conditions reduce energy costs and equipment costs, saving money. (1)

Q6 (b) [3]

- Lower operating temperatures (enabled by the catalyst) mean less fossil fuel is burned to heat the reaction. (1)
- This reduces carbon dioxide (and other) emissions associated with generating that energy. (1)
- Catalysts can also increase selectivity, reducing unwanted by-products/waste. (1)

Q6 (c) [2]

- A fine powder or supported catalyst has a much larger surface area (per unit mass) than a solid block. (1)
- This provides more active sites for reactant molecules to adsorb onto, increasing the rate of the catalysed reaction and making better use of (often expensive) catalyst material. (1)

Q7 (a) [3]

- A cross is drawn on paper placed under a flask; the reactants are mixed in the flask and a stopclock started. (1)
- The flask is viewed from above and the time taken for the cross to no longer be visible is recorded. (1)
- A pale yellow precipitate of sulfur forms during the reaction, which makes the solution increasingly cloudy/opaque, obscuring the cross. (1)

Q7 (b) [2]

- Independent variable: concentration of sodium thiosulfate. (1)
- Dependent variable: time taken for the cross to disappear (or 1/time as a measure of rate). (1)

Q7 (c) [2]

- Temperature (kept constant, e.g. using a water bath). (1)
- Volume/concentration of hydrochloric acid, and total volume of the reaction mixture (using water to top up as thiosulfate concentration is varied). (1)

Q7 (d) [2]

- Judging by eye exactly when the cross "disappears" is subjective. (1)
- Different observers (or the same observer on different runs) may judge the endpoint slightly differently, reducing the reliability/precision of the results. (1)

Q7 (e) [3]

- The time taken for the cross to disappear would decrease (the reaction would be faster). (1)
- At a higher temperature, particles have more kinetic energy and move faster, increasing collision frequency. (1)
- A greater proportion of collisions now have energy $\geq E_a$, so more collisions are successful, increasing the rate and shortening the time. (1)

Q8 (a) [2]

- A shorter time to produce the fixed volume corresponds to a faster reaction. (1)
- So "1/time" increases as the reaction gets faster, making it directly proportional to (a valid measure of) rate. (1)

Q8 (b) [3]

- A straight line drawn through the origin. (2)
- Positive gradient, extending across the given concentration range. (1)

Q8 (c) [3]

- At zero concentration, there are no reactant particles present. (1)
- With no particles, no collisions between reactant particles can occur. (1)
- With no collisions, the rate of reaction must be zero, so the graph passes through the origin. (1)

Q9 [6] — Level of response

- **Level 3 (5–6):** Explains both effects correctly and completely, clearly distinguishing the change in collision frequency (concentration) from the change in the proportion of successful collisions (temperature), using the Maxwell–Boltzmann distribution appropriately.
- **Level 2 (3–4):** Explains one effect fully and the other partially, or both partially with some confusion between frequency and proportion of successful collisions.
- **Level 1 (1–2):** Generic statements about "more energy" or "more collisions" without clear distinction between the two mechanisms.

Indicative content: *Doubling concentration doubles the number of particles per unit volume, which doubles the frequency of all collisions; since the Maxwell–Boltzmann distribution and E_a are unaffected by concentration, the proportion of collisions that are successful stays the same, so the rate roughly doubles in proportion to the concentration. Raising temperature by 10 °C increases the average kinetic energy of particles, shifting the Maxwell–Boltzmann distribution so a disproportionately larger fraction of particles now have energy ≥ E_a (the area under the curve beyond E_a increases sharply, not linearly, with a small temperature rise); both collision frequency and the proportion of successful collisions increase, causing a much larger (often roughly doubling) increase in rate from a comparatively small temperature change.*

END OF MARK SCHEME · 88 marks